Cost and Benefit Analysis for Climate-Smart Soil practices in Western Kenya

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Abbreviations and acronyms

BAU	business as usual
CBA	cost and benefit analysis
CDF	cumulative density function
CIAT	International Center for Tropical Agriculture
CSA	climate-smart agriculture
CSA-PF	climate-smart agriculture – prioritization framework
CSS	climate-smart soil
FAO	Food and Agriculture Organization of the United Nations
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit [German Agency for International Cooperation]
IRR	internal rate of return
NGO	non-governmental organization
NPV	net present value
PP	payback period
SIRR	social internal rate of return
SNPV	social net present value
SSA	Sub-Saharan Africa

Definition of terms

To avoid confusion, especially to non-specialists, we provide below a pragmatic definition of a few technical words used in this report.

Adoption costs are costs associated specifically to the introduction of the climate-smart agriculture (CSA) practices into the farming system. Three categories of adoption costs are recognized: installation cost, maintenance cost, and operation cost.

> **Installation costs** are initial costs carried out once at the beginning of the adoption process, such as buying and planting the trees in the case of the agroforestry system, or buying a zero-tillage planting machine if adopting the no-till way to prepare the seed bed. In many CSA practices, these costs represent a sizeable investment in terms of allocated resources.
>
> **Maintenance costs** are recurrent costs carried out periodically (for example, yearly). They are important for keeping the CSA practice working well over their entire lifetime. Examples include pruning, weeding, cleaning stonewalls, etc.
>
> **Operation costs** are costs associated with the consequences of introducing a CSA practice on the outputs/activities affected by the CSA practice (mostly, but not necessarily, associated harvesting costs). In the case of the agroforestry where harvesting trees takes place at the end of the lifetime, operation costs imply some harvesting costs that are not included in the maintenance cost flow.

A **discount rate** is the cost of capital or the amount of interest due per period as a result of using capital. This interest is the discount rate, which reflects the perceived riskiness of a cash flow in an investment. For instance, the interest on an amount lent or borrowed depends on the principal sum (i.e., capital). The main purpose of a discount rate is to account for the loss of economic efficiency of an investor due to risk. A discount rate is used by the investors because it provides them with a way to account and compensate for their risk when choosing an investment. Therefore, discount rates offer, with each choice, a buffer to provide for the chance of failure in an investment over time as well as many investments in a portfolio. Consequently, if an investor chose to use a high discount rate to discount the future cash, it just means that the investor is willing to pay less today for future cash. It is usually included in the calculation as a measure to prevent an investor from becoming “calculator rich” without actually increasing personal wealth. As used in this study, a discount rate represents the cost of capital in terms of premium incurred due to the risks associated with changing a practice for the farmer.

Net present value (NPV) (sometimes referred to as net present worth (NPW)) is a measurement of the profitability of an investment or a project that is calculated by subtracting the present value of cash outflows (including initial cost) from the present values of cash inflows over a period of time. The present value (sometimes referred to as the present discounted rate) is the value of an expected income stream determined as of the date when the valuation takes place. The present value is always less than or equal to the future value because money has the potential to earn interest, a characteristic referred to as the time value of money, except during times of negative interest rates, when the present value will be more than the future value. The NPV, as used in this report, shows whether a CSS practice is profitable or not by comparing the amount of money that a farmer has invested today with the present value of the expected future return from the implementation of a CSS practice.

Internal rate of return (IRR) on an investment or project is the "annualized effective compounded return rate" (sometimes referred to as the rate of return) that sets the net present value of all cash flows (both positive and negative) from the investment equal to zero. The "annualized effective compounded return rate" is a profit on an investment over a period of time, expressed as a proportion of the original investment. The time period is typically a year, in which case the rate of return is referred to as annual return. In other words, IRR is the discount rate at which the net present value of future cash flows is equal to the initial investment, and it is also the discount rate at which the total present value of costs (i.e., the negative cash flows) equals the total present value of the benefits (i.e., the positive cash flows).

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Abstract

Most of the countries in sub-Saharan Africa (SSA), including Kenya, depend heavily on agriculture for income and food security. Any effort aiming to sustain and improve the productivity in agriculture is, therefore, an important step towards improving the livelihoods of many households. Soils are integral to the function of food and fibre production. In addition, they have a large potential for sequestering carbon and mitigating greenhouse gases. The adoption of climate-smart soil practices can improve the soil-nitrogen cycle, enhance yield, soil fertility, crop productivity, improve soil biodiversity, and reduce soil erosion and water pollution. This could, in turn, help to boost food production, income and household ability to adapt. However, a review of published literature indicates a lack of in-depth empirical analysis on the costs and benefits associated with implementing these climate-smart soil (CSS) practices. Therefore, there is a gap about the cost effectiveness of adopting these practices – a key ingredient to the development of appropriate policies. The results presented in this paper attempt to bridge this knowledge gap, using an ex-ante cost and benefit analysis (CBA) to assess the cost-effectiveness of a few selected CSS practices in three counties in Western Kenya. The study's main goal is to assess costs and benefits of selected CSS practices as a step toward understanding whether it is beneficial or not – both from private and social points of view – for farmers who have implemented them.

1. Introduction

Climate change poses new challenges to the fight against sustainability of agrarian food security and livelihoods in sub-Saharan Africa (SSA) (Connolly-Boutin and Smit, 2015). Predictions indicate that in SSA, climate variability and change will have an adverse effect on agricultural production through declining crop yields (and crop yield-related losses) and livestock productivity caused by variability in rainfall, temperature and increased pests and diseases (Traore et al., 2013). Consequently, the food security and income generating opportunities for the farming households that rely mostly on agriculture may be negatively affected. Achieving food security will be a huge challenge in SSA, especially because at present there are over 280 million people still suffering from poverty and hunger (Fanzo and Pronyk, 2011) and the environment is still being degraded (Barbier, 2010). Apart from climate variability- and climate change-related risks, farmers in SSA are also faced with many biophysical and socio-economical challenges, most notably degrading land resource bases and poorly functioning markets (Driscoll et al., 2012; Mubaya et al., 2012). Therefore, apart from climate risk, the extent of yield decrease will also depend on other factors particularly on soil fertility and soil fertility management practices (Vanlauwe et al., 2010).

The Western region of Kenya is a major producer of agricultural commodities, such as crops and livestock products, in the country. This implies that major changes in productivity of key agricultural enterprises, resulting from the adverse effect of climate change or reduction in soil fertility, may lead to far-reaching implications on national food security and farmers' livelihoods. Therefore, the current challenge that the agricultural policy makers, researchers, and extension workers in Kenya face, is how to design policies, generate, and disseminate technologies and information that will offer greater resilience to the agricultural production systems under changing climatic conditions. In the recent years, efforts have been made by different national and international institutions to enhance farmers' resilience and adaptation to climate risks and to mitigate climate change in agriculture, thereby enhancing food security. An example here includes the Climate-Smart Soil (CSS) project funded by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) programme in three counties in Western Kenya, namely Siaya, Bungoma, and Kakamega. The selected three counties in Western Kenya are part of the GIZ programme on "Soil Protection and Rehabilitation for Food Security."

Soils are at the center of the GIZ programme. By supporting this programme, the GIZ-funded project at CIAT sought to take into account climate-smart interventions in the field of soils. This project intends to achieve its goals by providing empirical economic evidence that can inform the development of new climate-smart policies. Thereby advancing knowledge on the costs and benefits of sustainable soil fertility management. Such economic analysis can assist in the identification of potential investment portfolios, particularly for investors interested in transforming agricultural productivity through implementation of CSS practices that are aligned within the goal of climate-smart agricultural (CSA) practices. CSA, as defined by the Food and Agricultural Organization of the United Nations (FAO), comprises three main pillars: (i) sustainably increasing agricultural productivity and incomes, (ii) adapting and building resilience to climate change, and (iii) reducing and/or removing greenhouse gas emissions, where possible (FAO, 2012a). CSA is designed to implement sustainable agricultural development while addressing the food security and climate change challenges (FAO, 2010 ,2012b). This study is part of the GIZ programme in Kenya and is spearheaded by the International Center for Tropical Agriculture (CIAT).

1.1 The study objective and justification

This study assesses the costs and benefits of implementing CSS protecting practices in three counties in Western Kenya, namely Siaya, Bungoma, and Kakamega. In the context of this study, CSS is the abbreviation used for the CIAT-led "accompanying research project" to the GIZ programme on soil protection and rehabilitation. This project aim was to assess the "climate smartness" of the soil protection and rehabilitation measures. Examples of these measures include those practices that enhance soil protection, promote soil conservation, increase soil biomass, soil fertility, and reduce volatility in crop and livestock production. Such practices have the potential of improving households' ability to adapt to threats associated with climate change and variability (Mwongera et al., 2016). Specifically this study seeks to find out: i) what are the main costs and benefits associated with implementing the selected CSS practices, and ii) how the main social externalities associated with implementing the selected CSS practices can be incorporated in the estimation of benefits of selected CSS practices.

Most of the costs (i.e., labor, equipment, machinery, etc.) and benefits (i.e., enhanced ability to adapt, higher yields and income) for the majority of the implemented practices in agriculture are borne by individual farm households (Dallimer et al., 2016; Sain et al., 2016). Other benefits (i.e., improved water, air quality, reduction in disease spread, etc.) and costs (i.e., increased GHG emissions associated with the implemented practices) are experienced by the society at large (Balana et al., 2012). Since most of the major farm management decisions, including whether or not to implement a specific agricultural practice, takes place at the individual household farm system with always limited resources, there is a need to conduct an in-depth analysis to help us understand whether the practices that farmers implement are beneficial or not and to recognize the associated tradeoffs. Furthermore, given the diversity of farming systems in Western Kenya (Koge et al., 2016), there is a need for research into areas that can help farmers (and policy makers) to identify context-specific practices that can improve household livelihoods while supporting adoption of CSS practices for integration into future development planning, given the limited resources that can be brought forward, hence this study.

This report is organized as follows. The next section briefly reviews the theoretical basis of cost-benefit analysis (CBA). In section 2, we introduce the study area, explain how the CSS practices were selected, describe the data collection process and summarize how CBA analysis was implemented. The main CBA results are contained in section 3. In section 4, we discuss the main results while section 5 concludes with a general discussion and the way forward

1.2 Theoretical underpinning of CBA in climate-smart soil practices analysis

Economic theory postulates that economic trade-offs are unavoidable when scarce resources are allocated to a specific use (Balana et al., 2012). Households motivated by private interests, search for some guiding economic tools that can help them allocate their resources optimally in order to achieve their objectives (Sain et al., 2016). However, even in cases where decisions are made privately, the economic consequences may involve a series of externalities and trade-offs that necessitates careful accounting of the social impacts of the decision (Goulder and Kennedy, 1997). CBA is an applied economic tool that guides economic agents in resource allocation or investments project decision or policy alternatives (Almansa and Martnez-Paz, 2011; van Wee, 2012). CBA techniques are used to estimate the sum of, in present terms, the future flow of benefits and costs of society resource allocation decisions or policy alternatives for the purpose of establishing the worthiness of investment in a stipulated activity. It can also inform the economic efficiency to the decision maker (Ward, 2012). In many instances, CBA is applied in natural resource conservation policies (Balana et al., 2012; Marta-Pedroso et al., 2007; Mishra and Rai, 2014; Sun et al., 2013; Ward, 2012) and provision of environment services (Atkinson and Mourato, 2008; Torres et al., 2010). The rational for CBA is rooted in the principle of potential compensation, commonly known as Kaldor-Hicks criterion (Hicks, 1939; Kaldor, 1939). The principle states that an action is more efficient if those that are made better off could potentially compensate those that are made worse off and lead to a Pareto optimal[1] outcome. In cases where the benefit of an action spreads over time, decisions are based on comparing the present value of benefits and costs.

With regard to decisions related to implementation of CSS practices, the implementation of a particular practice results in, for instance, differences in the stock and flow of the benefits – e.g., yield and income – in the practice under consideration. The role of CBA is to measure the benefits and costs of the differences. Consequently CBA enables the comparison of two scenarios: the scenario with the implementation of the CSS practices and the scenario without it (or business as usual). However, the application of the CBA in CSS practices also poses few challenges. For example some of the goods and services are not traded directly in the market and attaching a value to them is difficult. Moreover, attaching an accurate and true economic value to a large number of environmental goods and services still remains a challenge. Nevertheless, CBA remain an important analytical tool in most investment decisions (van Wee, 2012).

1 Relating to a distribution of wealth such that any re-distribution or other changes that are beneficial to one individual is detrimental to one or others.

2. Materials and methods

2.1 The study area

This study was conducted using data from three counties: Bungoma, Kakamega, and Siaya (See Appendix 1 for detailed description of the study site).

2.2 The prioritization process and selection of the CSS practices

The data used in this study was collected from County agricultural officials, extension officers, representatives of NGOs working on soils protection and key resource farmers from the three counties. Data collection process involved two main steps: 1) identification of the climate-smart soil practices to be taken into consideration, and 2) conducting a household survey. The CSA-PF prioritization process that involved a workshop, focus group discussions and experts interviews was used to identify CSS practices and investment portfolios. Farmers, extension officers, County agricultural officials and representatives of NGOs working in the area were involved in the CSA-PF prioritization process. To probe on the investment portfolio, the stakeholders were divided into two broad groups: the farmers and the experts. The expert group comprised of extension officers, County agricultural officials and NGO representatives. The CSA-PF process comprised several steps. Step one involved validation of the main farm typologies developed for the study site by Koge et al., (2016). These farm typologies were i) small-scale mixed subsistence farming, ii) medium-scale mixed with commercial dairy, iii) medium-scale mixed with commercial horticulture, iv) medium-scale mixed with commercial cereals, and v) large-scale commercial farming. Step two involved identification and listing of the already existing (and new) CSS practices that are applicable in the different farm typologies through focus group discussion. Step three involved evaluation of the listed practices using ten indicators in the CSA goals of productivity, resilience, low emission and development. The main goal of step three was to generate a short list comprising three high-interest CSS practices for each farm typology (Table 1). Step four involved identifying common practices prioritized by both the farmers and the experts in each farm typology. Step five involved conducting an indepth household survey for the selected CSS practices. In summary, steps one to four resulted in a list of 40 practices, out of which only eight practices were shortlisted – based on the priority ranking based on the 10 indicators CSA-PF – for CBA analysis (Table 1). The rest of the paper focuses on the results derived using data from step ‘five’, outlining the detailed costs and benefits for short-listed – by farmers and experts for each farm typology – CSS practices.

Table 1: List of practices, by farm typology, prioritized for economic evaluation

Farm typology	Practice	Specification
Small-scale mixed subsistence farming	Intercropping	Cultivation of two or more crops simultaneously on the same field, especially in alternating row
	Organic manure	Use of products derived from animal matter or vegetable matter (e.g., compost, manure etc.) as fertilizer
Medium-scale with mixed commercial dairy	Agroforestry	Introduction of trees or shrubs among crops or pastureland to create more diverse, productive ecologically sound and sustainable land use
Medium-scale with commercial horticulture	Improved tomatoes seeds	Introduction of seeds produced by cross-pollinated plants to improve characteristic of the resulting plants, such as higher yields, greater uniformity and disease resistance
	Organic manure[2]	Use of products derived from animal matter or vegetable matter (e.g., compost, manure etc.) as fertilizer
Medium-scale mixed with commercial cereals	Improved hybrid seeds	Introduction of seeds produced by cross pollinated plants to improve characteristic of the resulting plants, such as higher yields, greater uniformity and disease resistance
	Inorganic fertilizer	Introduction of materials of natural or synthetic origin (other than liming materials) such as phosphate fertilizer, nitrogen that is applied on soils or plant tissues (usually leaves) to supply one or more plant nutrients that essential to sustain plant growth
Large-scale commercial farming	Liming	Introduction of calcium and magnesium rich materials on soils to neutralize soil acidity and increase activity of bacteria in the soil

2 Organic manure comprises different type of manure: cow dung manure, goat manure and slurry.

3 Inorganic fertilizer comprised of the use of P_2O_5 phosphate fertilizer (DAP), application of Nitrogen fertilizer to top-dress.

2.3 Data collection process

Household survey data was collected using a structured questionnaire. The questionnaire asked for: 1) general information about the site, 2) household age, gender, education level, and farming experience, 3) farm activities (without intervention), 4) implemented CSS practices such as improved seeds, agroforestry, inorganic fertilizers, liming, organic manure, 5) yield, prices, inputs and costs of the implementing farming activities (both before and after intervention), 7) household financial information, and 8) environmental and socioeconomic effects.

Prior to the data collection exercise, a team of six enumerators were trained on questionnaire administration, translation and recording of the georeferenced household location and responses.

The enumerators also participated in pre-testing of at least two questionnaires and shared their initial experiences with translation. The team leader and the enumerators shared the experiences gathered during the pre-test, including going through the questionnaire used during pre-test together. All unclear issues were identified and rectified.

Enumerators were paired in each county for ease of the coordinating household interviews. A total of 88 households were interviewed (Figure 1). Preferably, in each farm household, the household head was interviewed. However, in farm households where the household head was absent, another household member belonging to the farm household who had attained over 18 years and who had been involved in farming for at least 10 years was interviewed.

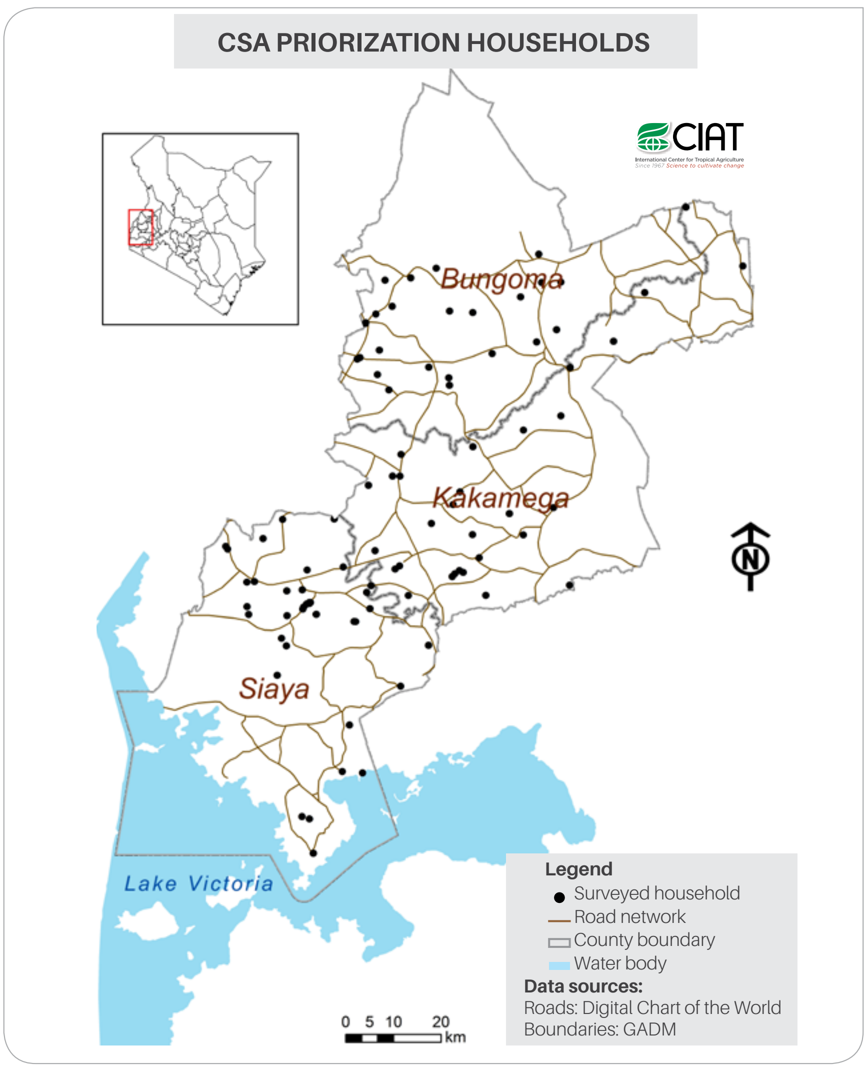

Figure 1: A map of Kenya (left upper corner) showing the three counties: Bungoma, Kakamega, and Siaya (our study area) and the interviewed farm households (black dots).

2.4 Cost-benefit analysis

CBA was used in evaluating the CSS practices by determining the relative profitability of alternative practices by comparing their differences in terms of flow of benefits and cost over their lifecycles. CBA is mainly applied in assessing the profitability of investments in private and public sector (Claus and Rousseau, 2012). The Net Present Value (NPV) and the Internal Rate of Return (IRR) are the two commonly used indicators for CBA (Juhász, 2011). The NPV – determined by the minimally expected yield – shows how the amount of wealth growth has been accumulated by the investment during its duration, but it does not inform about the real profitability of capital investment. In other words, NPV is the incremental flow of net benefits generated by the alternatives being compared over their lifecycle. However, the IRR is the discount rate that makes the present value of the flow of future net benefits exactly equal to zero (the discount rate that make NPV = 0). The advantage of IRR is that it doesn't necessarily need to specify the cost of capital (i.e., interest rate). Once calculated, the IRR can be compared with a range of possible values to determine the profitability under different scenarios. A higher IRR depicts an investment with a higher potential. An investment is therefore declared profitable if its IRR is larger than the opportunity cost of money (i.e., the discount rate). In this study a discount rate of 9%, was used as an estimate of the opportunity cost of money for capital by banks and saving and credit organization based on data from households survey in Western Kenya.

This study uses farm average values of the variables in the calculation of the IRR. That is, no measurement of the variability or uncertainty associated with the resulting IRR was computed. From this study it is thus difficult to say with certainty the risks involved when implementing a specific practice (see Appendix 2 for detailed description of the CBA model, variables used, and valuation of externalities).

3. Results

3.1 Descriptive results

A total of 88 households were interviewed for this study. However, responses from eight households were discarded because farm income and yield data were not available. Therefore, only 80 respondents were considered in the final CBA analysis. These respondents were evenly distributed in the three counties (i.e., 36, 31, and 33% in Kakamega, Bungoma, and Siaya, respectively. Majority (75%) of the households were male-headed households, with a mean farming experience of 21 years (with a standard deviation [stdev] = 5). The level of education attained by majority of the households' head was secondary school (51%), followed by tertiary level (32%) and primary school (20%).

The distribution of the households that had implemented the use of the eight practices were evenly distributed across the three counties (Siaya, Bungoma and Kakamega), except for liming, use of improved seeds and intercropping in the small-scale mixed subsistence farming, medium-scale commercial with horticulture and large-scale commercial farming respectively (Table 2). The lifecycle for the eight CSS practices ranged between four and 19 years (stdev ranged between 0 and 9 years). The use of inorganic manure (in the medium-scale with commercial cereals) had the longest lifecycle (19 years), followed by use of liming (12 years), the use of improved seeds (in the medium-scale mixed with commercial dairy) and intercropping (Table 3). Use of organic manure in the small-scale mixed subsistence farming had the shortest lifecycle (5 years). The mean number of crops affected by the eight CSA practices under investigation in this study (Appendix 4) was 4.1 (stdev = 1.2). As expected, the mean farm size for the implemented practices was larger (i.e., 2.3 ha) for large-scale commercial farmers (Appendix 5), while medium-scale mixed with commercial horticulture practicing the use of organic manure had the least farm area (i.e., 0.62 ha). The mean number crop grown by studied households across the three counties is 5.3 (stdev = 1.7).

Table 2: Distribution of the households by farm typology and by practices in Bungoma, Kakamega, and Siaya

Farm typology	CSS practice	# of respondents (households) by county			
		Bungoma	Kakamega	Siaya	All counties
Small-scale mixed subsistence farming	Organic manure	4	4	4	12
	Intercropping	2	4	1	7
Medium-scale mixed with commercial dairy	Agroforestry	6	4	6	18
Medium-scale mixed with commercial horticulture	Improved seeds	2	2	3	8
	Organic manure	4	3	3	10
Medium-scale mixed with commercial cereal	Improved seeds	3	3	3	9
	Inorganic manure	2	3	3	8
Large-scale commercial farming	Liming	1	4	3	8
Total		25	29	26	80

Table 3: Mean and standard deviation (in years) of the lifecycle of each practice by farm typology and practice in Bungoma, Kakamega, and Siaya

Farm typology	CSS practice	Bungoma	Kakamega	Siaya	
		Mean (stdev)	Mean (stdev)	Mean (stdev)	Overall mean
Small-scale mixed subsistence farming	Organic manure	4 (2)	8 (3)	4 (2)	5
	Intercropping	4 (1)	11 (7)	15 (0)	10
Medium-scale mixed with commercial dairy	Agroforestry	8 (4)	7 (2)	6 (3)	7
Medium-scale mixed with commercial horticulture	Improved seeds	6 (0)	14 (8)	9 (8)	10
	Organic manure	4 (3)	7 (2)	7 (3)	6
Medium-scale mixed with commercial cereals	Improved seeds	6 (3)	10 (4)	10 (0)	9
	Inorganic manure	14 (6)	12 (6)	19 (6)	15
Large-scale commercial farming	Liming	12 (1)	12 (0)	12 (9)	12

During the last 24–36 months prior to the field survey, 40% of the households' head had acquired credit for financing implementation of new technologies in their farms. The main sources of credit is non-governmental organization (NGO's) (39%), saving credit cooperative societies (SACCOs) (21%), banks (19%), cooperative groups (9%) and other sources (12%). Other sources of credit consist of family relations, Safaricon M-Shwari services, traders, and community based organizations (CBO's). The two main types of credit accessed by the households were cash (55%) and inputs (45%). Credit repayment period ranged between three and 36 months with a mean interest rate of 9% (stdev = 6%) per annum.

3.2 Private profitability

The CBA calculation considered only the farm activities that were affected by the CSS practices. The cost of BAU scenario was, therefore, taken as the cost incurred by farmers to implement and maintain a farming activity per hectare before the adoption of the CSS practice. The cost of the CSS practice captured the cost of adopting,[4] implementing and maintaining the affected activity on a typical one hectare piece of land. Therefore, although the farmer may have had many activities taking place on the farm, and in area less than one hectare, our calculation are based on the adoption, implementation and maintenance of CSS practice on one hectare piece of farm for the affected farm activities. Therefore, the CBA analyses uses one hectare as the unit of analysis.

The analysis in this report is based on the average inputs and output for all activities affected by the eight CSS practices across the three counties, rather than within each county. For the BAU scenario, input and output values were computed using five years recall data prior to the implementation of the CSS practice. The input and output data for each of activity affected by the implementation of the CSS were computed from household survey data and triangulated using information from the literature. The lifecycle period capture the period from the when farmer implement the CSS practice to when the farmer stops the CSS practice so that he/she can start all over again or implement a new CSS practice. The private NPV[5] for each CSS practice is therefore estimated as the sum total of the value of the enhanced yield, reduced labor, less the cost of implementation, less maintenance and less operation costs, while social NPV is a sum total of private NPV and the enhanced social benefits.

All the eight CSS practices studied have a positive NPV and their IRR is greater than the discount rate over their lifecycles (Table 4). Implementing a CSS practices that involved the use inorganic fertilizer and improved seeds by the medium scale mixed with commercial cereal farmers had the highest NPV. This implies that the benefits accrued from after implementing the eight practices use of over their lifecycles across the three counties outweighed the cost. The IRR for all the eight practices is higher than the discount rate of 9%, meaning they are all profitable. The result showed that the practice requires the highest initial investment cost and a time lag of between two to three years for increased productivity and income to be realized fully (Table 4).

Table 4: The mean and standard deviation (in years) of the lifecycle of each practice by farm typology and practice in Bungoma, Kakamega, and Siaya

Farm typology	CSS Practice	NPV (9%)	IRR (%)	Payback Period (years)
Small-scale mixed subsistence farming	Organic manure	2,857	36	2
	Intercropping	5,218	58	3
Medium-scale mixed with commercial dairy	Agroforestry	6,216	63	4
Medium-scale mixed with commercial horticulture	Improved seeds	4,346	48	4
	Organic manure	4,899	48	4
Medium-scale mixed with commercial cereals	Improved seeds	6,767	66	3
	Inorganic fertilizer	6,730	70	3
Large-scale commercial farming	Liming	5,164	59	3

NB: CSS stands for climate-smart soil practices. NPV and IRR stands for Net Present Value and Internal Rate of Return, respectively (a detailed explanation of the same is provided under Definition of terms on preliminary pages). Payback period is the time duration that the project takes to repay its initial capital in full.

4 See Definition of terms on preliminary pages.

5 See Definition of terms on preliminary pages.

Although the cost of adopting and implementing the use of improved seed for farmers in the medium-scale with commercial cereals was high (US$1,550 ha^{-1} yr^{-1})[5], it had the highest NPV (US$6,767 ha^{-1}), for the duration of its lifecycle (i.e., 9 years) examined and a payback period of three years. For farm typology, medium scale with commercial horticulture, the NPVs associated with use of improved seeds and use of organic manure were US$4,346 and US$ 4,899 ha^{-1} respectively. The use of improved seeds and use of organic manure had a similar IRR (48%) and payback period of four years, regardless of the slightly higher implementation cost for improved seeds (US$1,347), compared to the use of organic manure (US$1,114).

The NPVs of adopting and implementing the use of organic manure and intercropping in the small-scale mixed subsistence farm typology were US$2,857 and US$5,218 respectively. The benefit of adopting and implementing agroforestry, over a seven years period generated a NPV of US$ 4,436, with a payback period of about four years. Three of the eight CSA practices under investigation (Table 4) require a PP of about four years for the economic returns to be realized. Three other practices have a PP period of 3 years, while only one practice had a payback of two years.

Table 5: Estimated implementation, maintenance and operation cost by practice and farm typologies across all counties

Farm typology	CSS Practice	Implementation cost (US$ ha^{-1})	Maintenance (US$ ha^{-1} yr^{-1})	Operation cost (US$ ha^{-1})
Small-scale mixed subsistence farming	Organic manure	84	73	60
	Intercropping	693	457	31
Medium-scale mixed with commercial dairy	Agroforestry	400	234	145
Medium-scale mixed with commercial horticulture	Improved seeds	1,347	272	200
	Organic manure	1,114	588	459
Medium-scale mixed with commercial cereals	Improved seeds	1,550	510	211
	Inorganic fertilizer	756	455	142
Large-scale commercial farming	Liming	743	202	297

NB: CSS stands for climate-smart soil practices. The definition of implementation, maintenance and operation costs is provide in page iv and v. A detailed breakdown of the different cost categories that constitutes implementation, maintenance and operation costs are provided in Appendix 6.

3.3 Environmental and social benefits

Regarding environmental and social externalities benefits, we computed the average change in biodiversity as a result of introduction of trees on farm based on the estimation of change in biodiversity (Henry et al., 2009). The total value of biodiversity was approximately US$170 ha^{-1} for farm households that had adopted the use of agroforestry practice. Although some of the other seven practices could also potentially have an impact on biodiversity, we did not estimate their impact due to lack of information and their limited impact.

The estimated value of the carbon sequestered and reduction of air contamination by the adoption of

6 A detailed description of the different cost categories considered for implementation, maintenance and operation costs are provided in Appendix 6.

agroforestry practice over the entire lifecycle is equal to US$700 and US$ 670 ha^{-1} yr^{-1} respectively. Relating to the value of nitrogen fixed due to implementation of the intercropping (where beans and cowpeas were present) in the small-scale mixed subsistence farm typology, was estimated at about of US$ 81 ha^{-1} yr^{-1} In all the CSS practices where legumes were grown, the value of nitrogen fixed was estimated to range between US$ 11 and 15 ha^{-1} yr^{-1}. The estimated value of soil improvement due to adoption of agroforestry practice was estimated at US$ 13 ha^{-1} yr^{-1}. Although the remaining seven practices adopted could also potentially have an impact on soil improvement, it was difficult to determine their magnitude due to lack of data on their impact.

Estimate on social externalities (mainly labor and employment) showed that there was an increased in labor as a result of implementation all the eight practices (Table 6). The liming practice in the large-scale commercial farm typology, for instance, labor for implementation increased by 14 man-days ha^{-1}. For intercropping practice in the small-scale mixed subsistence farmers, labor for implementation increased by 57 man-days ha^{-1} during the first year. This results to a mean increase of about 29 man-days ha^{-1} across all the eight practices, which translate to an average increase of about US$131 ha^{-1} across all the eight practices. There is also a general increase in maintenance labor of about 15 man-days ha^{-1} yr^{-1} across all the eight practices, translating to an average increase of US$ 69 ha^{-1} yr^{-1} across all the eight practices (Table 6).

Table 6: Estimated change in the labor and value of labor for the eight CSS practices

Farm typology	Practice	Increased in labor (Man days ha^{-1})		Increase in the value of labor (US$ ha^{-1})	
		Implementation	Maintenance	Implementation	Maintenance
Small-scale mixed subsistence farming	Organic manure	18	12	81	54
	Intercropping	57	28	256.5	126
Medium-scale mixed with commercial dairy	Agroforestry	49	10	220.5	45
Medium-scale mixed with commercial horticulture	Improved seeds	19	10	85.5	45
	Organic manure	27	19	121.5	85.5
Medium-scale mixed with commercial cereals	Improved seeds	36	27	162	121.5
	Inorganic fertilizer	13	11	58.5	49.5
Large-scale commercial farming	Liming	14	6	63	27
	Average	29	15	131	69

NB: The value of one labor (Man-days) is estimated at 450KSh (US$4.5). The exchange rate at the time of field survey was 1US$ = 100KShs (Government of Kenya, 2016).

4. Discussion

For policy makers and development practitioners, there are questions that linger in their mind when it comes to investment especially in agriculture. This is because an investment is worth embarking on only if it can generate some positive returns to the farmer and/or be beneficial to the society or community where the investment is likely to take place. When a practice is profitable to an individual farmer, chances are that other households may implement it thereby having a larger and long-term impact to the society at large. It is against this background that this study sought to evaluate the cost and benefits of implementing selected climate-smart soil practices that can promote soil conservation, increase soil biomass and reduce volatility in crops and livestock production in Western Kenya. Most often when decision-makers are interested in evaluating the investment options for the purpose of development planning, CBA is used (de Bruin et al., 2013). CBA has also been used assessing the impact of change in policies such as spatial planning (de Bruin et al., 2013), land use change (McDonald, 2001), transportation (Hyard, 2012), and recently on adaptation to climate smart practices (Nassopoulos et al., 2012; Sain et al., 2016). At the same time because of the uncertainties associated with the expected impact of some policies such as those associated with climate change, controversies and debates surrounding the use of CBA are never lacking. Some authors questions whether CBA is the right approach in decisions that relate to climate change policies (Bromley, 1990; Goulder and Kennedy, 1997). Other debates surrounding the use of CBA are associated with values used in its computation such as the discount rates (Almansa and Martínez-Paz, 2011), and the level of analysis especially when one is interested in the impact of up scaling or downscaling. Scrieciu et al., (2013) notes that decision making by farmers on whether to adopt about a particular project need to be informed by CBA analysis, despite the uncertainties associated with it. Nevertheless, there is a need to acknowledge and communicate the strength and weaknesses associated with the CBA analysis, in order for it to be able to appropriately address development and investment decisions (van Wee, 2012).

The CBA analysis presented in this study was conducted at the level of individual households as the main beneficiary of private NPVs and social NPVs, and we limited our analysis to both provision of ecosystem services and social externalities related to only farm activities that were affected by the implementation of the eight CSS practices implemented by the sampled farmers in Siaya, Bungoma and Kakamega. Farmers in these three counties contend with different economic, social and environmental context, and receive different amount of institutional support for climate smart soil practices, which interact to influence household decision making and adoption (Dallimer et al., 2016). In this study, however, all farmers were assumed to be in a similar economic, social and environmental context.

Previous studies have used CBA to assess the viability of the cost and benefits of soil land management practices implementation (Dallimer et al., 2016) in the three counties separately and across all counties. Although the present study was also conducted in the same counties, and for practices associated with soil, the uniqueness of the present study stems from the mix of farm typologies and type of practices considered for demand driven and timely use by the development practitioners and policy makers. These practices provide options that yield both social and economic benefits, so that they continue to deliver benefits now and in the future, thereby improving households' ability to adapt to climate variability and change (CNT, 2010; de Bruin et al., 2013; Dittrich et al., 2016). Although the present study focuses on CSS practices, we did not incorporate in the CBA analysis the impacts of climate change on the selected CSS practices. Nevertheless, the expected impact of the selected CSS practices on the CSA goals of mitigation, productivity and adaptation was addressed in the prioritization phase.

All the eight CSS practices analyzed are profitable when all the cost and benefits are considered in that they all had positive private NPVs (Table 4). However, all the practices had a payback period of 2 years or more. For example in the small scale mixed subsistence farm typology, the use of organic manure and intercropping had a payback period (PP) of two and three years respectively. The PP of intercropping is considerably long for small-scale subsistence farmers. This finding suggests that for small-scale subsistence farmers to implement some of these practices, they need to be supported with short-term livelihood options, and an enabling environment. The implementation of organic manure in small-scale mixed subsistence farming typology had an IRR of about 36% and a PP of 2 years, meaning that this practice is favorable choice for farmers in the small-scale subsistence farming. Implementation of improved seed is a good choice for farmers in the medium scale mixed with commercial horticulture and commercial cereals typologies because it has a high IRR, however, it has a considerable PP. The implementation of improved seeds by farmers in the medium-scale mixed with commercial cereals typology incurred the highest cost[7] (US$1,550 see Table 5), it has a high IRR (i.e. 66%) and a payback period of 3 years (Table 4) suggesting that for farmers to implement this practice, they need to have a diversified short-term livelihood strategies.

Although, all the analyzed practices are profitable, they had PP of 2 years or more meaning there is a need for farmers to be provided with some support for example inputs at subsidized input prices, low interest rates on credit and improved roads to enhance access to major markets where output can fetch better prices. Such steps can easily boost food security, household income, adaptability and agriculture production at the national level.

The finding in this study showed that implementation of organic manure and intercropping in the small-scale mixed subsistence farm typology and agroforestry incurred relatively lower implementation cost (Table 5) and had relatively high NPVs and an IRR greater than the discount rate, meaning that these three practices has a high potential for boosting household food security, household income and hence the ability to adapt. These suggest that the economic case for scaling out agroforestry, the use of organic manure, intercropping, use of improved seeds, use of inorganic fertilizer and organic manure across the different farm typologies are all-promising. However, because of the long PP in some of the practices may act as hindrance for the uptake of these practices, there is a need for appropriate institutions and policy support to be provided.

In term of externalities, agroforestry practice that had the highest externality benefits (Table 7). This is because of the contribution of trees to the improvement of soil quality, carbon sequestration, increase in biodiversity and improvement of the air quality. The high uncertainty associated with the physical assessment of the externalities, and consequently their economic valuation for all the CSS practices studied was overcome by using mean of a range of values, from published work when needed (for example improvement in soil quality, air quality and carbon sequestration). Of all the CSS practices assessed, agroforestry had the highest social net present value (Table 7) because it had the largest impact in terms of carbon sequestration, improvement of air and soil quality. This practice could therefore be promoted for uptake because it is worth investment both for public good and its role in mitigation. The implementation of inorganic fertilizer and improved seeds in the medium-

7 See Appendix 6 for additional details on what constitute the implementation, maintenance and operation costs.

scale mixed with commercial cereals also had high social net present value. This is because these practices reduces the losses associated with pest and diseases, and the resulting use of pesticides. Most of the analyzed CSS practices required the use of additional labor (Table 6) for implementation and annual maintenance compared to BAU practice. This suggest that implementation of the studied CSS practices has a potential of creating employment for youth and women.

Table 7: The average value (in US$) of social profitability of the implementation of CSS practices per hectare over their lifecycle period

Farm typology	Climart-smart Soil (CSS) Practice	Social net present value (SNPV)	SIRR
Small-scale mixed subsistence farming	Organic manure	3,981	52
	Intercropping	5,937	46
Medium-scale mixed with commercial dairy	Agroforestry	13,315	135
Medium-scale mixed with commercial horticulture	Improved seeds	4,418	48
	Organic manure	6,562	62
Medium-scale mixed with commercial cereals	Improved seeds	6,840	67
	Inorganic fertilizer	12,126	130
Large-scale commercial farming	Liming	5,264	60

NB: SNPV is a summation of flows of value of externalities to the flow of private net benefits. SIRR stands for social internal rate of return. CSS stands for climate-smart soil practice.

As with any CBA study, the main constraint in this study is mainly associated with the degree of uncertainty relating to the impact of the implementing CSS practices on crop yield and minimizing negative benefits associated with BAU practices. To overcome this limitation, we conducted on-farm surveys on farmers who had in the past practiced BAU, but implemented some of the selected CSS practice during the last 3-5 years, to be able to capture changes in yield on farms. We used an average real term price of between 2010 and 2015 to avoid problems associated with short-term price fluctuation. Because some of the CSS practiced had not been practiced long enough to measure the impact of implementing CSS practices, ex-ante and ex-post characteristics were mixed during the analysis. The limitations associated with subjectivity when setting the terms of analysis (Fischhoff, 2015), were overcome by selecting the CSS practices to be studied in a stakeholders workshop, where development practitioners and farmers were both present.

As it relates to the general finding of this study, since all the CSS practices analyzed had positive NPVs, and an average PP of 3.2 years, we think this provide a sufficient justification for the ministry of agriculture in the three counties to promote these CSS practices.

5. Conclusion and policy implications

With data from 80 households from three counties (Bungoma, Kakamega and Siaya), this study analyzed the benefits and cost of implementing eight CSS practices on smallholders' farms with varying opportunities and cost. Focusing mainly on the private and social net present values of these practices, our analysis indicates that implementing all the studied CSS practices across the three counties yield positive benefits. However, expected the cost of implementation and maintenance varies by practices. All the CSS practices studied also have different payback periods. These analyses therefore provide critical information for the ministry of agriculture in the three counties government to reassess the practice being promoted by county agricultural ministries in light of the associated benefits and tradeoffs. This study also provides an insights on the externalities and social benefits associated with the studied CSS practices, which help us to understand the potential of each practice as it relate to the three CSA goals of food security, adaptation and mitigation.

In the context of the study area this study provides a rationale that can be used as a basis for promoting selected CSS. That it is economically justifiable for households across the different farm typologies to adopt and implement the studied CSS practices. The study also confirms that there is need for policy and institutional support. Policy support could for example through subsidies for inputs such as fertilizer, farm equipment and machineries. Institutional support could be provided through supporting and facilitating agricultural interaction and learning between farmers, projects and agricultural extension officers.

References

Almansa C; Martínez-Paz JM. 2011. What weight should be assigned to future environmental impacts? A probabilistic cost benefit analysis using recent advances on discounting. Sci. Total Environ. 409:1305–1314. http://dx.doi.org/10.1016/j.scitotenv.2010.12.004

Atkinson G; Mourato S. 2008. Environmental cost-benefit analysis. Annual Review of Environment Resources 33:317–344. http://dx.doi.org/10.1146/annurev.environ.33.020107.112927

Balana BB; Muys B; Haregeweyn N; Descheemaeker K; Deckers J; Poesen J; Nyssen J; Mathijs E. 2012. Cost-benefit analysis of soil and water conservation measure: The case of exclosures in northern Ethiopia. Forest Policy and Economics 15:27–36. http://dx.doi.org/10.1016/j.forpol.2011.09.008

Barbier EB. 2010. Poverty, development, and environment. Environment and Development Economics 15(6):635–660. http://dx.doi.org/10.1017/S1355770X1000032X

Beattie B; Taylor CR. 1993. The Economics of Production, Reprint. ed. Krieger Pub. Co, Florida, USA.

Berck P; Geoghegan J; Stohs S. 2000. A Strong Test of the von Liebig Hypothesis. American Journal of Agricultural Economics 82:948–955. http://dx.doi.org/10.1111/0002-9092.00093

Bromley DW. 1990. The ideology of efficiency: Searching for a theory of policy analysis. Journal of Environmental Economics and Management 19(1):86–107. http://dx.doi.org/10.1016/0095-0696(90)90062-4

Claus K; Rousseau S. 2012. Public versus private incentives to invest in green roofs: A cost benefit analysis for Flanders. Urban Forestry & Urban Greening 11:417–425. http://dx.doi.org/10.1016/j.ufug.2012.07.003

CNT (Center for Neighborhood Technology). 2010. The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits. 80 p. http://bit.ly/1dSO2D3

Connolly-Boutin L; Smit B. 2015. Climate change, food security, and livelihoods in sub-Saharan Africa. Regional Environmental Change 16(2):385–399. http://dx.doi.org/10.1007/s10113-015-0761-x

Dallimer M; Stringer L; Orchard S; Osano P; Njoroge G; Wen C. 2016. Economics of Land Degradation (ELD) Kenya Study. Costs and benefits of sustainable soil fertility management in Western Kenya. Report for the Economics of Land Degradation Initiative. 40 p. http://bit.ly/2pnetHt

de Bruin K; Goosen H; van Ierland EC; Groeneveld RA. 2013. Costs and benefits of adapting spatial planning to climate change: Lessons learned from a large-scale urban development project in the Netherlands. Regional Environmental Change 14(3):1009–1020. http://dx.doi.org/10.1007/s10113-013-0447-1

Dittrich R; Wreford A; Moran D. 2016. A survey of decision-making approaches for climate change adaptation: Are robust methods the way forward? Ecological Economics 122:79–89. http://dx.doi.org/10.1016/j.ecolecon.2015.12.006

Driscoll DA; Felton A; Gibbons P; Felton AM; Munro NT; Lindenmayer DB. 2012. Priorities in policy and management when existing biodiversity stressors interact with climate-change. Climatic Change 111(3):533–557. http://dx.doi.org/10.1007/s10584-011-0170-1

Fanzo JC; Pronyk PM. 2011. A review of global progress toward the Millennium Development Goal 1 Hunger Target. Food and Nutrition Bulletin 32(2):144–158. http://dx.doi.org/10.1177/156482651103200207

FAO (Food and Agriculture Organization of the United Nations). 2012a. Mainstreaming climate-smart agriculture into a broader landscape approach. Second Global Conference on Agriculture, Food Security and Climate Change. Hanoi, Vietnam, 3-7 Sept 2012. Rome, Italy. 26 p. http://bit.ly/2p0uCTT

FAO (Food and Agriculture Organization of the United Nations). 2012b. The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome, Italy. 62 p. http://bit.ly/1fKJHiL

FAO (Food and Agriculture Organization of the United Nations). 2010. Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome, Italy. 41 p. http://bit.ly/2oShhjA

Fischhoff B. 2015. The realities of risk-cost-benefit analysis. Science 350(6260):aaa6516. http://dx.doi.org/10.1126/science.aaa6516

Goulder LH; Kennedy D. 1997. Valuing Ecosystem Services: Philosophical Bases and Empirical Methods, In: Nature's Services: Societal Dependence on Natural Ecosystems. Daily GC (ed.). Washington DC: Island Press. pp. 23–47.

Government of Kenya. 2016. Central Bank of Kenya. https://www.centralbank.go.ke/

Henry M; Tittonell P; Manlay RJ; Bernoux M; Albrecht A; Vanlauwe B. 2009. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agriculture, Ecosystems and Environment 129(1-3):238–252. http://dx.doi.org/10.1016/j.agee.2008.09.006

Hicks JR. 1939. The Foundations of Welfare Economics. The Economic Journal 49(196):696–712. http://dx.doi.org/10.2307/2225023

Hyard A. 2012. Cost-benefit analysis according to Sen: An application in the evaluation of transport infrastructures in France. Transportation Research Part A: Policy and Practice 46(4):707–719. http://dx.doi.org/10.1016/j.tra.2012.01.002

Juhász L. 2011. Net present value versus internal rate of return. Economics and Sociology 4(1):46–53. http//:dx.doi.org/10.14254/2071-789X.2011/4-1/5

Kaldor N. 1939. Welfare propositions of economics and interpersonal comparisons of utility. The Economic Journal 49(195): 549–552. http://dx.doi.org/ 10.2307/2224835

Kassam A; Friedrich T; Shaxson F; Bartz H; Mello I; Kienzle J; Pretty J. 2014. The spread of Conservation Agriculture: Policy and institutional support for adoption and uptake. Field Actions Science Reports. Vol. 7. http://factsreports.revues.org/3720

Koge JK; Birnholz CA; Birthe KP. 2016. The economics and climate-smartness of soil protection and rehabilitation in Western Kenya. Workshop report. International Center for Tropical Agriculture (CIAT); University of Leeds; Stockholm Environment Institute (SEI). 5 February 2016, Kisumu, Kenya.

Marta-Pedroso C; Domingos T; Freitas H; de Groot RS. 2007. Cost-benefit analysis of the Zonal Program of Castro Verde (Portugal): Highlighting the trade-off between biodiversity and soil conservation. Soil and Tillage Research 97(1):79–90. http://dx.doi.org/10.1016/j.still.2007.08.010

McDonald JF. 2001. Cost-benefit analysis of local land use allocation decisions. Journal of Regional Science 41(2):277–299. http://dx.doi.org/10.1111/0022-4146.00217

Mishra PK; Rai SC. 2014. A cost-benefit analysis of indigenous soil and water conservation measures in Sikkim Himalaya, India. Mountain Research and Development 34(1):27–35. http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00013.1

Mubaya CP; Njuki J; Mutsvangwa EP; Mugabe FT; Nanja D. 2012. Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia. Journal of Environmental Management 102:9–17. http://dx.doi.org/10.1016/j.jenvman.2012.02.005

Mwongera C; Shikuku KM; Twyman J; Läderach P; Ampaire E; Asten P Van; Twomlow S; Winowiecki LA. 2016. Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. Agricultural Systems 151:192–203. http://dx.doi.org/10.1016/j.agsy.2016.05.009

Nassopoulos H; Dumas P; Hallegatte S. 2012. Adaptation to an uncertain climate change: Cost benefit analysis and robust decision making for dam dimensioning. Climatic Change 114(3–4):497–508. http://dx.doi.org/10.1007/s10584-012-0423-7

Sain G; Loboguerrero AM; Corner-Dolloff C; Lizarazo M; Nowak A; Martínez-Barón D; Andrieu N. 2016. Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala. Agricultural Systems 151:163–173. http://dx.doi.org/10.1016/j.agsy.2016.05.004

Sun L; Lu W; Yang Q; Martín JD; Li D. 2013. Ecological compensation estimation of soil and water conservation based on cost-benefit analysis. Water Resources Management 27(8):2709–2727. http://dx.doi.org/10.1007/s11269-013-0268-5

Torres AB; Marchant R; Lovett JC; Smart JCR; Tipper R. 2010. Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation. Ecological Economics 69(3):469–477. http://dx.doi.org/10.1016/j.ecolecon.2009.09.007

Traore B; Corbeels M; van Wijk MT; Rufino MC; Giller KE. 2013. Effects of climate variability and climate change on crop production in southern Mali. European Journal of Agronomy 49:115–125. http://dx.doi.org/10.1016/j.eja.2013.04.004

van Wee B. 2012. How suitable is CBA for the ex-ante evaluation of transport projects and policies? A discussion from the perspective of ethics. Transport Policy 19(1):1–7. http://dx.doi.org/10.1016/j.tranpol.2011.07.001

Vanlauwe B; Bationo A; Chianu J; Giller KE; Merckx R; Mokwunye U; Ohiokpehai O; Pypers P; Tabo R; Shepherd KD; Smaling EMA; Woomer PL; Sanginga N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook on Agriculture 39:17–24. http://dx.doi.org/10.5367/000000010791169998

Ward FA. 2012. Cost–benefit and water resources policy: A survey. Water Policy 14:250–280. http://dx.doi.org/10.2166/wp.2011.021

Appendices

Appendix 1. Detailed description of the study site

Kakamega County borders Vihiga County to the south, Busia and Siaya County to the West and Bungoma to the North. The County lies between latitude 0° 16'N and longitude 34° 45'E and covers an area of approximately 3050.3 km^2. The County receives bimodal rainfall averaging 2200–1300mm annually. The rainfall is evenly distributed all year round; with March and July receiving heavy rains while December and February receives light rains. The temperatures range is between 18° C and 29°C. The altitude ranges from 1,240–2,000 meters above sea level (masl) (Government of Kenya, 2013a). The County has 12 subcounties (Government of Kenya, 2013a). Most farmers grow sugarcane, maize and tea as cash crops. Food crops include maize, bean, cassava, finger millet and sorghum. The average farm size is 3 ha and 10 ha for small-scale and large-scale farmers respectively (Government of Kenya, 2013a). The livestock bred in the County include cattle, sheep, goats, and pigs.

Siaya County is one of the six counties in Nyanza region. It is bordered by Busia County to the north, Vihiga and Kakamega counties to the northeast, Kisumu County to the southeast. It lies between latitude 0° 26'S to 0° 18'N and longitude 33° 58'E and 34° 33'E. The County experiences a bi-modal rainfall, with long rains falling between March and June and short rains falling between September and December. On the highlands, the annual rainfall ranges between 800–2,000 mm while lower areas receive between 800–1,600 mm (Government of Kenya, 2013b). The County is divided into six administrative subcounties namely Siaya, Bondo, Rarienda, Gem, Ugunja, and Ugenya (Government of Kenya, 2013b). The main food crops include maize, sorghum, millet, beans, cowpeas, cassava, sweet potatoes, groundnuts and finger millets. Cash crops comprise of cotton, rice, sugarcane and groundnuts. Livestock kept include cattle, goats, sheep, pigs, and poultry.

Bungoma County borders the republic of Uganda to the Northwest, Trans-Nzoia County to the Northeast, Kakamega County to the East and South East, and Busia County to the West and South West. It lies between latitude 0° 28' and latitude 1° 30’ North of the Equator, and longitude 34° 20' E and 350 15' E of the Greenwich Meridian. The annual rainfall in the County ranges from 400 mm (lowest) to 1,800 mm (highest) (Government of Kenya, 2013c). The County is divided into nine subcounties and agriculture is the main occupation and source of income. The main food crops include maize, beans, finger millet, sweet potato, banana, Irish potato and assorted vegetables. Sugarcane, cotton, palm oil, coffee, sunflower and tobacco are grown as cash crops. The main livestock breeds in the county include cattle, sheep, goats, donkeys, and pigs.

Appendix 2. The model, variable used for modeling, and valuation of externalities and social impacts

A.2.1 The Model

When conducting a CBA, it is important to specify the point of view of analysis. In this study the CBA estimates the private profitability of implementing CSS practices by the farmer mainly. Nevertheless, the public interest is also taken into account by estimating separately the value of some of the beneficial external effects including carbon sequestration, reduction in soil erosion, reduction in air contamination, reduction in pest and diseases and improvement of soil quality. Though important for consideration by policy-makers in evaluating public economic trade-offs, in this study, the value of externalities was computed separately from private profitability calculation.

The flow of the net benefits of replacing farmers practice (business as usual [BAU]) by CSS practice per hectare were estimated using (Eq. 1)

$$NPV_j^{\text{css-bau}} = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left[\sum_{j}^{j} P_{jt} * \Delta Y_{jt}^{\text{css-bau}} - \sum_{j=1}^{j} * \Delta C_{jt}^{\text{css-bau}}\right] \quad (1)$$

Where P_{jt} represents the price of commodity "j" in time t; $\Delta Y^{\text{css-bau } jt}$ represents the annual change in commodity "joss yield between the BAU farmers practice with the CSS practices; and $\Delta C^{\text{css-bau } jt}$ represents the annual change in cost of implementing the CSS instead of BAU practice, r is the discount rate representing the opportunity costs and T represents the time horizon in the analysis (i.e., lifecycle period).

To model the effects of adopting a CSS practice on crop yield, it was assumed that the implemented practices would improve the soil fertility, improve water infiltration, improve soil quality at the farm level. Practices with these outcomes are likely to improve uniformity in production and increase pest and disease resistance through improved soil quality and thereby increase crop yields (Altieri and Nicholls, 2003; Lal, 2015). However, it can take a considerable period for the yield response to be realized due to adoption of CSS practices. Furthermore, the response is also determined by other biophysical characteristics of the soil such as current soil fertility and degradation.

Therefore to take the physical response of crop yield due to adoption of CSS into account, we assumed that the response curve follows a linear plateau preceded by a lag between when the practice is implemented and the time the yield start to be realized (Beattie, B., Taylor, 1993; Berck et al., 2000).The main costs that were included in the CBA analysis are installation and maintenance costs. Installation cost are costs incurred by the farmer at the adoption of the CSS practice while maintenance cost are the cost – most often computed on a yearly basis – required to ensure proper performance of the practice throughout its lifetime (i.e., since when the practice starts until it is completed).

A.2.2 Variables used for modeling

Cost benefit analysis requires specifying variables considered as random or nonrandom variable. Nonrandom variables are those variables that are evaluated at the mean or most frequent (mode). Random variables are variables that can take any values over the entire range of possible values in a given cumulative distribution function. The variables modeled in this study include: installation costs, maintenance costs, market prices, changes on crop and livestock yield (i.e., yield response), time (i.e., practice life cycle, time (in years) when the crop and/or livestock yield starts to increase and reaches maximum as a result of implementing the CSS practice, and a discount rate. Installation and maintenance cost are considered as random variables because they capture variability – determined largely by the local context (e.g., soil) – in production across households in the study sites. Yield response is considered a random variable because it can vary a lot across households as it is affected by the implemented practice. Market prices are considered nonrandom variable because they do not vary much across households in a given study site. Time and discount rate are considered nonrandom variables because they are largely determined by the characteristics of the implemented practice.

A.2.3 Random variable distribution function

To capture the uncertainty of the response of crop yields as a result of implementing a CSS practice, it was assumed that the yield follows a triangular probability distribution characterized by three parameters: the maximum, most likely and the maximum value (Figure 1). Triangular distribution are widely used in cases where there are data limitation about the true value of the parameter exists. In this study data on minimum and maximum and most likely values to reveal the triangular distribution of the technology variability, installation, and maintenance costs were collected from 88 key resource farmers.

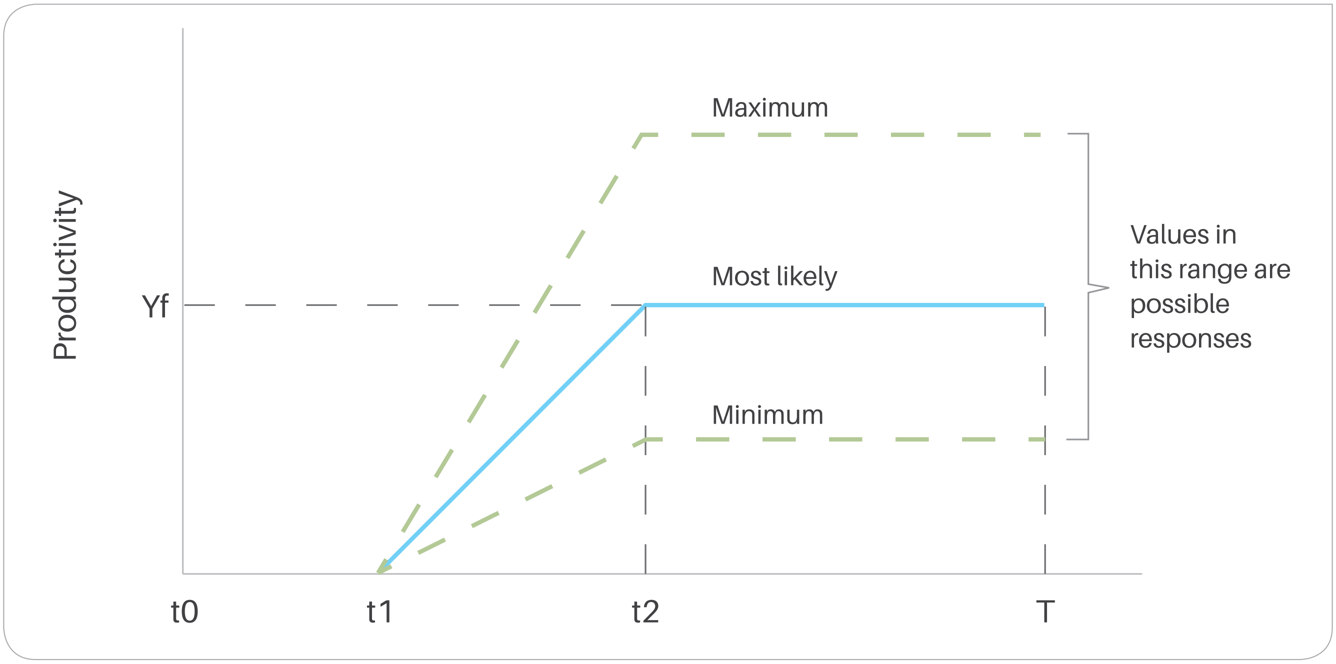

Figure A1: Parameters characterizing triangular probability distribution. Adapted from: Beattie and Taylor (1993).

A.2.4 Valuation of externalities

In addition to the private benefits associated with the implementation of CSS practices considered in the profitability estimation, the implemented practices provide other diverse external effects relating to GHG emissions, air quality, soil erosion, water retention, soil fertility and biodiversity that were identified as relevant by 60 CSS stakeholders during the workshop (Table A1). Evidence from published literature confirms that implementation of the a practices in question has the potential to provide these external benefits (Bowe and van der Horst, 2015; Day, 2008; Manrique et al., 1993; Pagiola et al., 2007; Sain et al., 2016).

Table A1: Some of the external effects associated related to the selected CSA practices

Practice	External effects						
	Biodiversity	GHG emissions	Carbon sequestration	Pests and diseases	Improves air quality	Soil fertility	Water retention
Agroforestry [8]	Biological increase of habitats for multiple species of crops and organisms	Decreases GHG emissions	Increases carbon sequestration	No significant impact	Reduces erosion of soil particles by acting as a windbreak thereby improving air quality	Increases soil fertility through decaying biomass and amount of carbon stored in the soil	Increases water infiltration by slowing flow of water
Improved seeds	No significant impact	No significant impact	No significant impact	Reduces the impact of pests and diseases	No significant impact	No significant impact	No significant impact
Organic manure	Biological increase of habitats for multiple organisms	Increases GHG emissions (N_20)	No significant impact	No significant impact	No significant impact	Improves soil structure and fertility	Improves ability of soil to hold water
Intercropping	Difficult to determine	No significant impact	No significant impact	No significant impact	No significant impact	Increases soil fertility	No significant impact
Inorganic fertilizer (DAP, urea)	No significant impact	Increases GHG emissions in the long term (through denitrification of nitrates and emission of nitrates to N_20	No significant impact	No significant impact	No significant impact	No significant impact	No significant impact

8 Agroforestry, as used in this study, refers to a land use system in which trees or shrubs (with a time span of more than one year) are grown in association with agricultural crops or pastures, at the same time (i.e., not in a time sequential) as the crops (Tengnas, 1994).

The value of external effects in this study was estimated using the weighted amount of change in the externality as a result of the introduction of the CSS practice and its associated shadow price.[9] A shadow price represents the marginal value that a person is willing to pay or (willing to accept) for a given positive (negative) external effects. There exist a number of methods developed for estimating the shadow prices for different externalities (Brey et al., 2011; Ekins, 1993; Power, 2010; Swinton et al., 2007). Inclusion of price is warranted because ecosystem services contribute to economic wellbeing in ways that extend beyond aesthetic amenities (Imhoff et al., 2004; MEA, 2005). To estimate the value of the benefits associated with the identified externalities we used the contingent valuation method (CVM), since it is the most versatile nonmarket valuation method (Brey et al., 2011; Power, 2010). CVM is survey based economic technique for the valuation of non-marketed resources impacting positively or negatively to the environment (Diamond and Hausman, 1994).

A.2.5 Data

The main source of information for this study were a structured questionnaire and a review of literature particularly to fill the gaps relating to information on externalities. Data collection using structured questionnaire was carried out between May and June 2016 to 88 farm households, in three counties. The ministry of agriculture in the three Counties provided the primary sampling frame of 180 farm households. The survey gathered data on the adoption, implementation and maintenance of the eight selected CSS practices during the CSA-PF workshop. Data was also collected on BAU practices – for a period of 5 years based on recall – that households applied on their farms before the adoption of CSS practices. The information collected during the survey included input and yield quantities and market prices for all the farm activities that is affected by the implemented CSS practices. A comparison of BAU and CSS yields for all the crops affected by the CSS practices showed an increase in yield (Appendix 3). Most of the CSS practices had been implemented more than three years. The CBA analysis is therefore a mix of ex-ante and ex-post nature. Ex-post because farm households under study have implemented the CSS practices. Ex-ante because impact on the ecosystem services for some of the practices given their lifecycles had not yet been experienced.

Yield

To estimate the response curve (Figure A1) of the after implementation of CSS practice for the affected crops (Appendix 3), information from the household survey was used to estimate the initial yield (Y_o) for the BAU practice (Appendix 3). The values for most likely, maximum (Y_{min}) and minimum (Y_{max}) value (Figure A1) for the yield characterizing the distribution of yield response of using a CSS practice were calculated from the households surveys.

Biodiversity

Evidence from published work shows that biodiversity in agro-ecosystems may contribute to diversification of products, diets and to the stability of household income (Brookfield, H., Stocking, M., Brookfield, M., 2002). To estimate change in biodiversity, we relied on land use change at the farm level (Henry et al., 2009; Pagiola et al., 2007). The main idea for this valuation method is that it provides indicators to represent the quantity of the environmental services provided by changes in land use patterns. A score is assigned based on the potential of various land use types to support or enhance biodiversity. For example a score of 1.3 is assigned to farm forest because it provides a larger volume of environmental services. A score of 0.49 is assigned to land use that provides the lowest environmental services for example a food crop (Henry et al., 2009). Valuation of environmental services associated with a specific land use therefore is made based on the proportional increase (i.e., after implementation of the CSS practice) relative to the baseline (i.e., BAU practice). To estimate the value of the change in biodiversity induced by the implementation of each CSS practice, it was assumed that the value of true parameter follows a uniform distribution with a minimum of zero and a maximum value of the value the key resource farmers were willing to pay for the biodiversity benefits associated with a specific land use. Values were then estimated by multiplying the change in the biodiversity index from the adoption of

9 In business application, shadow price is the opportunity cost of an external effect or activity whose actual price is not known, or if known does not reflect the actual market price..

each practice by the shadow price of biodiversity. The willingness to pay value for a unit change in biodiversity ranged between US$5 and US$80 with an average of US$26 ha^{-1}.

Carbon sequestration

For any CSS practice that the farmer may choose to implement, carbon sequestration externalities is considered as a public good of global interest in the 21st century (Lal, 2008). Carbon sequestration is defined as the amount of carbon that can be additionally stored in an agroec0system (Bernoux et al., 2006). Therefore, a change in land use practice that enhances carbon sequestration offers private benefits such as high organic matter and carbon in the soil, which increases carbon balance in the soil. Carbon sequestration is valued as a function of credit emission reductions (CERs), based on the difference between the amount of carbon stored in the systems after implementation of a CSS practice and the BAU (i.e., carbon stored in the system before the implementation of the CSS practice) (Arnalds, 2004). To assign a monetary value to carbon sequestered as a result of implementing a practice, we used Kenya Agricultural Carbon Project (KACP)[10] financing estimates of US$10 per t CO_2 sequestered in Kenya. An estimate on carbon sequestered due to implementation of practices was gathered from the literature. Due to high level of uncertainty of value of carbon sequestered by the selected practices, agroforestry was the only practice considered for carbon sequestration in this study because trees represent the most important carbon pool contributing about 81 and 55% of total above ground farm carbon in Vihiga and Siaya respectively (Henry et al., 2009). Agroforestry also increases the amount of carbon trapped in soils by adding organic matter where the greenhouse gas is stored. This in turn improves the soil structure and significantly contributes to crop rooting, health and drainage. For this study, we assumed that adoption of agroforestry practice in one hectare of land sequestered approximately 77 t CO_2e ha^{-1} based on the work of Henry et al., (2009) in Siaya and Vihiga Counties.

Soil fertility

The implementation of some CSS practices can also increase positive externalities in form of soil fertility from decomposing organic matter and nitrogen fixation by legumes – even though not all legumes fix nitrogen (Vanlauwe and Giller, 2006) – and nutrient cycling (Aisbett and Kragt, 2010; Brooker et al., 2015; Wang et al., 2014). We assumed that the amount of nitrogen fixed per hectare by different crops grown in the different CSS practices implemented by farmers were as shown in Table A2. Valuation of increased soil fertility (i.e., amount of kgN fixed per hectare) was then conducted using opportunity cost, where the estimated value of gained soil fertility (N) was assumed to save approximately 0.5[11] US$ per Kg of N gained. The value of soil fertility benefits per unit area was then estimated by multiplying the proportion of the area in which respective leguminous crop occupy, in the implemented CSS practice, by value of nitrogen gained in a hectare. The amount of N contained in organic manure was calculated based on the weight of the total organic manure applied on one hectare for a period of on year. To do this we assumed that the total nitrogen contained in one tonne of organic manure is approximately 4.5 kg and that 20% of this nitrogen is lost through leaching.

10 KACP project compensates for Sustainable Agriculture Land Management (SALM) practices that capture and store greenhouse gases – or carbon-dioxide equivalent using payment received from world bank administered BiCarbon fund (Kassam et al., 2014; Seeberg-Elverfeldt, 2010).

11 The N-value is based on the unit price of urea in 2014–2015, US$25 per 50 kg of urea.

Table A2: The estimated amount of nitrogen fixed by legumes

Grain legume	Scientific name	Intercropped	Nitrogen fixed (KgN ha^{-1} yr^{-1})
Cow peas	*Vigna unguiculata*	Sole crop	33
Cow peas	*Vigna unguiculata*	Intercrop	18-73
Groundnut	*Arachis hypogea*	Sole crop	55.8
Pigeon peas	*Cajanus cajan*	Sole crop	54.1
Pigeon peas	*Cajanus cajan*	Intercrop	12
Soya beans	*Glyxine max L*	Sole crop	35.8
Soya beans	*Glyxine max L*	Intercrop	2-60
Common beans	*Phaseoulus Vulgaris*	Intercrop	20-80
Mung beans (green grams)	*Vigna radiata*	Sole	12
Pigeon pea/groundnut	*Vigna unguiculata/ Arachis hypogea*	Intercrop	45-83

Source: (Lindemann and Glover, 2003; Njira et al., 2012; One Acre Fund, 2015).

Pests and diseases

Introduction of some CSS practices – for example intercropping and crop rotation – may lead to direct or indirect reduction in pests and diseases (Aisbett and Kragt, 2010; Veres et al., 2013). Farmers consider reduction of pests and diseases a positive benefit because the presence of pests not only reduces yield of existing growers of crops but also the options for new growers to grow that crop. The valuation of the benefit arising from a reduction in pests and disease from implementation of the CSS practice was estimated using opportunity cost. That is by calculating the expenditure that the households makes in order to avoid losses associated with diseases and pests. We used an average value of US$50 ha^{-1} yr^{-1} as expenditure that the households make to avoid diseases. That is, cost of control (US$10–16 ha^{-1}), potential damage (US$10–16 ha^{-1}), losses of production of about 20–60% and loss of production of about 1% to due to birds for example (Ellis and S.N. Putt, 1981; Rose et al., 1997). These estimates are based on the assumption that pest control by native insects could reduce production losses a result of predation by pest species.

Soil quality

For the household practicing agroforestry, we estimated an improvement of soil quality following Sandhu et al (2008) study. The amount of soil formed was computed, then multiplied by the market price of soils (Eq. 2)

$$[V_{SoilF} = (Q_{earth}) + Q_{invert})] * P_{soil}$$

$$= (N_{earth} * 0.0002 + Q_{invert}) * P_{soil} \qquad (2)$$

Where V_{SoilF} is the price of soil is produced ha^{-1} y^{-1}, Q_{earth} is the amount of soil formed by earthworms, Q_{invert} is the amount of soil formed by invertebrates, P_{soil} is the market price of soil ($ ton^{-1}), N_{earth} is the number of earthworms in the soil and 0.0002 is the weight of 1 earthworm (kg). According to Sandhu et al., (2008) the weight of 1 earthworm equals 0.2 g and a ton of earthworm produces 1000kg soil ha^{-1} yr^{-1}. In their study, Price and Gordon (1999) suggested that the number of earthworms equals 119–394 m^{-2} and biomass equals 245–557 g m^{-2} in poplar intercropping. Therefore, assuming that each earthworm produces a biomass of about 250 g m^{-2}, then there is about 2.5 ton of biomass produced by earthworm per hectare. Based on Sandhu et al., (2008) study that 1 ton earthworm produces 1000kg soil ha^{-1} yr^{-1}, then the total soil produced in agroforestry is 2.5 ton ha^{-1} yr^{-1}. In this analyses we assumed that the price of topsoil is approximately KShs 500 per ton (i.e., similar to a ton of red soil in Kiambu County).[12]

12 http://bit.ly/2oVzD31

Air quality

Evidence from the published literature indicates that trees are effective in removing air pollutants such as NO_2, SO_2, dust and other particulate matter (Nowak et al., 2006). In their study, Dwyer et al., (1992) found that urban forestry with about 90,000 trees had a potential of removing 154 tons (i.e., 1.67 kg pollutant by one tree per year) of particulate matter annually. If we assume that an agroforestry tree is able to remove about 0.70 kg pollutant per tree per year (since they are not grown in an urban setting), and assuming that it cost US$10 to remove a kilogram of pollutant, a tree provides a service worth US$7 per year. In a 100 tree ha^{-1} plot we then obtain the annual air quality maintenance service provided by tree by multiplying the dollar amount with the total number of tree per hectare.

Water retention

Evidence from published literature indicates that the use of organic manure improves soil structure, which eventually reduces water runoff by about 10–50% and increase infiltration by about 10–20% (Rawls et al., 2003). Although this is a long term effect these factors combines to reduce soil erosion on field where organic manure is used by between two thirds and four-fifths (Vanlauwe et al., 2015). It is a challenge to place monetary value on the water lost as runoff and nutrients contained in the eroded soil, because they are in part displaced to other location of the farm where they remain available for crop production. If we assume that there exist a significant difference in the costs of replacing water on farms where organic manure is not used. These costs account for money saved in farms where organic manure is practiced. Using the information collected from farmers, the cost of hiring, operating and maintaining a water pump for irrigating a hectare cost US$10 day^{-1}. Assuming that annual crops takes on average six months per year on the farm, we then obtain the annual cost of irrigating the farm by multiplying the dollar amount with 17.5% of the average number of days that crops takes to mature by cost of irrigating per day. We used survey data to calculate the increase in labor for installation and maintenance using the average local cost of labor (US$4.5 $person^{-1}$ day^{-1}).

Social impact

The potential impact of CSS practices on the employment was the main reason why we considered the social impact. We assumed that in adopting, implementing and maintaining a CSS practice requires the use of additional labor the one already being used on the business as usual activities on the farm. The survey data was, therefore, used in estimating the increase in labor for installation and maintenance. To determine the economic impact of labor we multiplied the increase in man-days by the average local cost of labor (US$4.5 man-$day^{-1}$ day^{-1}).

Appendix 3

The mean value of the BAU (Y_0) yield for different crops, and the final yield (Y_1) under the CSS practices obtained from the field survey and/or literature.

		Improved seeds	Use of organic manure
Medium-scale mixed with commercial horticulture			
Kales	Y_0 Kales (Kg/ha)	831	800
	Y_1 Kales (Kg/ha)	2,760	2,000
	Annual change (Kg)	1,929	1,200
Sweet potatoes	Y_0 Sweet potatoes (Kg/ha)	1,200	1,163
	Y_1 Sweet potatoes (Kg/ha)	2,000	2,276
	Annual change (Kg)	800	1,113
Cowpeas	Y_0 Cowpeas (Kg/ha)	600	1,348
	Y_1 Cowpeas (Kg/ha)	1,200	2,924
	Annual change (Kg)	600	1,576
Traditional vegetables	Y_0 Trad. Vegetables (Kg/ha)	669	951
	Y_1 Trad. Vegetables (Kg/ha)	1,277	1,608
	Annual change (Kg)	608	657
Medium-scale mixed with commercial cereals			
		Inorganic fertilizer	Improved seeds/seedlings
Maize	Y_0 Maize (Kg/ha)	1,000	636
	Y_1 Maize (Kg/ha)	2,000	2,000
	Annual change (Kg)	1,000	1,364
Beans	Y_0 Beans (Kg/ha)	600	600
	Y_1 Beans (Kg/ha)	1,220	1,680
	Annual change (Kg)	620	1,080
Bananas	Y_0 Bananas (Kg/ha)	1,229	1,229
	Y_1 Bananas (Kg/ha)	2,695	2,695
	Annual change (Kg)	733	733

(Continues)

(Continued)

Sorghum	Y_0 Sorghum (Kg/ha)	NA	775
	Y_1 Sorghum (Kg/ha)	NA	1,330
	Annual change (Kg)	NA	555
Cassava	Y_0 Cassava (Kg/ha)	720	NA
	Y_1Cassava (Kg/ha)	1,674	NA
	% yield change	954	NA
Medium-scale mixed with commercial dairy			
		Liming	Agroforestry
Trees	Y_0 Poplar/ha	NA	755
	Y_1 Poplar/ha)	NA	1,468
	Annual change (Kg)	NA	178
Napier grass	Y_0 Napier grass (Kg/ha)	NA	3,876
	Y_1Napier grass (Kg/ha)	NA	4,929
	Annual change (Kg)	NA	1,053
Maize	Y_0 Maize (Kg/ha)	1,652	755
	Y_1 Maize (Kg/ha)	2,681	1,468
	Annual change (Kg)	1,029	713
Beans	Y_0 Beans (Kg/ha)	700	511
	Y_1 Beans (Kg/ha)	1,500	750
	Annual change (Kg)	800	178
Green grams	Y_0 Green grams (Kg/ha)	600	NA
	Y_1 Green grams (Kg/ha)	1000	NA
	Annual change (Kg)	400	NA
Soybeans	Y_0 Soybeans (Kg/ha)	864	NA
	Y_1 Soybeans (Kg/ha)	1,540	NA
	Annual change (Kg)	676	NA

NB: NA stands for not applicable. Source of Y_0 = Authors survey; Y_1 = Authors survey, experts survey and literature.

Appendix 3 (continued)

The mean value of the BAU (Y_0) yield for different crops, and the final yield (Y_1) under the CSS practices obtained from the field survey.

		Small-scale mixed subsistence farming	
		Intercropping	Use of organic manure
Maize	Y_0 Maize (Kg/ha)	519	800
	Y_1Maize (Kg/ha)	1,000	2,127
	Annual change (Kg)	481	664
Beans	Y_0 Beans (Kg/ha)	575	525
	Y_1 Beans (Kg/ha)	1000	1000
	Annual change (Kg)	425	237
Bananas	Y_0 Bananas (Kg/ha)	NA	923
	Y_1 Bananas (Kg/ha)	NA	1,500
	Annual change (Kg)	NA	283
Groundnut	Y_0 Groundnut (Kg/ha)	668	NA
	Y_1 Groundnut (Kg/ha)	800	NA
	Annual change (Kg)	132	NA
Sugarcane	Y_0 Soybeans (Kg/ha)	NA	376
	Y_1Soybeans (Kg/ha)	NA	688
	Annual change (Kg)	NA	156

NB: NA stands for not applicable. Source of Y_0 = Authors survey; Y_1 = Authors survey, experts survey and literature.

Appendix 4

The number of crops (#) affected by the different CSA practices by farm typology and practice in Bungoma, Kakamega, and Siaya.

Farm typology	CSA practices	Bungoma	Kakamega	Siaya
		# crops	# crops	# crops
Small-scale mixed subsistence farming	Organic manure	5	4	4
	Intercropping	4	4	3
Medium-scale mixed with commercial dairy	Agroforestry	4	5	5
Medium-scale mixed with commercial horticulture	Improved seeds	4	3	4
	Organic manure	3	5	6
Medium-scale mixed with commercial cereals	Improved seeds	1	4	4
	Inorganic manure	7	5	4
Large-scale commercial farming	Liming	3	5	5

Appendix 5

The average farm size by farm typology and practice in Bungoma, Kakamega and Siaya.

Farm typology	CSA practices	Bungoma	Kakamega	Siaya	All counties
		Mean (stdev)	Mean (stdev)	Mean (stdev)	Mean (stdev)
Small-scale mixed subsistence farming	Organic manure	0.60 (0.31)	0.41 (0.34)	0.88 (0.77)	0.64 (0.57)
	Intercropping	0.77 (0.95)	0.53 (0.36)	4.18 (4.56)	0.94 (1.75)
Medium-scale mixed with commercial dairy	Agroforestry	1.25 (0.69)	0.51 (0.65)	1.02 (3.12)	0.84 (1.91)
Medium-scale mixed with commercial horticulture	Improved seeds	0.99 (0.57)	0.54 (0.49)	0.28 (0.22)	0.66 (0.65)
	Organic manure	0.76 (0.37)	0.45 (0.54)	0.23 (0.22)	0.62 (0.81)
Medium-scale mixed with commercial cereals	Improved seeds	0.93 (0.51)	1.47 (1.15)	1.50 (1.63)	1.08 (1.20)
	Inorganic manure	1.13 (0.86)	0.81 (0.86)	0.68 (0.42)	0.71 (0.65)
Large-scale commercial farming	Liming	5.65 (5.56)	1.99 (3.95)	2.37 (2.07)	2.33 (3.33)

Appendix 6

Detailed estimates of implementation, maintenance and operation cost by practice and farm typologies across the three counties.

Farm typology	CSS Practice	Implementation cost		Maitenance cost		Operation cost	
		Categories	Cost (US$ ha^{-1} yr^{-1})	Categories	Cost (US$ ha^{-1} yr^{-1})	Categories	Cost (US$ ha^{-1} yr^{-1})
Small-scale mixed subsistence farming	Farmyard manure	Machinery and equipment	6	Machinery and equipment	40	Inputs	8
		Inputs	0	Inputs	24	Services out	0
		Services	16	Services	(45)	Labor out	52
		Labor	54	Labor	54		
		Transfer costs (10%)	8		0		
	Total		**84**		**73**		**60**
	Intercropping	Machinery and equipment	35.5	Machinery and equipment	22	Inputs	17
		Inputs	(136)	Inputs	(197)	Services out	0
		Services	604	Services	506	Labor out	14
		Labor	126	Labor	126		
		Transfer costs (10%)	63		0		
	Total		**693**		**457**		**31**
Medium-scale mixed with commercial dairy	Agroforestry	Machinery and equipment	0	Machinery and equipment	0	Inputs	37
		Inputs	179	Inputs	95	Services out	0
		Services	77	Services	0	Labor out	108
		Labor	108	Labor	140		
		Transfer costs (10%)	36				
	Total		**400**		**234**		**145**

NB: Machinery and equipment comprises of wheelbarrow, water pump, chuff-cutter, panga, spade, shovel, ox-plough etc. Inputs comprises of herbicides, seeds, pesticides, fertilizers etc. Services comprises of oiling of machinery and equipment, repair of work out equipment, harvesting etc. Labor comprise of the labor used to execute different activities on the farm such as spraying, operating a machine or equipment etc. Transfer cost comprises about 10% of the sum of the cost in machinery, inputs, services and labor transfer paid by the farmer either in cash or an opportunity cost.

Appendix 6 continued

Detailed estimates of implementation, maintenance and operation cost by practice and farm typologies across the three counties.

Farm typology	CSS Practice	Implementation cost		Maintenance cost		Operation cost	
		Cost categories	Cost (US$ ha^{-1} yr^{-1})	Cost categories	Cost	Categories	Cost (US$ ha^{-1} yr^{-1})
Medium-scale mixed with commercial horticulture	Improved seeds	Machinery and equipment	220	Machinery and equipment	133	Inputs	105
		Inputs	627	Inputs	165	Services out	8
		Services	0	Services	(32)	Labor out	88
		Labor	377	Labor	5.5		
		Transfer costs (10%)	122		0		
	Total		**1,347**		**271.8**		**200**
	Farmyard manure	Machinery and equipment	220	Machinery and equipment	58	Inputs	167
		Inputs	680	Inputs	421	Services	192
		Services	(5)	Services	23	Labor	98
		Labor	122	Labor	86		
		Transfer costs	101		0		
	Total		**1,114**		**588**		**458.6**

NB: Machinery and equipment comprises of wheelbarrow, water pump, chuff-cutter, panga, spade, shovel, ox-plough etc. Inputs comprises of herbicides, seeds, pesticides, fertilizers etc. Services comprises of oiling of machinery and equipment, repair of work out equipment, harvesting etc. Labor comprise of the labor used to execute different activities on the farm such as spraying, operating a machine or equipment etc. Transfer cost comprises about 10% of the sum of the cost in machinery, inputs, services and labor transfer paid by the farmer either in cash or an opportunity cost.

Appendix 6 continued

Detailed estimates of implementation, maintenance and operation cost by practice and farm typologies across the three counties.

Farm typology	CSS Practice	Implementation cost		Maintenance cost		Operation cost	
		Cost categories	Cost (US$ ha^{-1} yr^{-1})	Cost categories	Cost	Categories	Cost (US$ ha^{-1} yr^{-1})
Medium-scale mixed with commercial cereals	Improved seeds	Machinery and equipment	700	Machinery and equipment	106	Inputs	161
		Inputs	583	Inputs	244	Services out	0
		Services	5	Services	(5)	Labor out	50
		Labor	121	Labor	165		
		Transfer costs (10%)	141		0		
	Total		**1,550**		**510**		**211**
	Inorganic fertilizer	Machinery and equipment	83	Machinery and equipment	63	Inputs	110
		Inputs	480	Inputs	167	Services out	12
		Services	2.5	Services	130	Labor out	20
		Labor	122	Labor	94		
		Transfer costs (10%)	69		0		
	Total		**756**		**455**		**142**
Large-scale commercial farming	Liming	Machinery and equipment	133	Machinery and equipment	105	Inputs	127
		Inputs	291	Inputs	42	Services out	87
		Services	0	Services	0	Labor out	83
		Labor	252	Labor	55.4		
		Transfer costs (10%)	68				
	Total		**743**		**202**		**297**

NB: Machinery and equipment comprises of wheelbarrow, water pump, chuff-cutter, panga, spade, shovel, ox-plough etc. Inputs comprises of herbicides, seeds, pesticides, fertilizers etc. Services comprises of oiling of machinery and equipment, repair of work out equipment, harvesting etc. Labor comprise of the labor used to execute different activities on the farm such as spraying, operating a machine or equipment etc. Transfer cost comprises about 10% of the sum of the cost in machinery, inputs, services and labor transfer paid by the farmer either in cash or an opportunity cost.

References

Aisbett E; Kragt M. 2010. Valuing ecosystem services to agricultural production to inform policy design: An Introduction. http://bit.ly/2p9y66j

Altieri MA; Nicholls CI. 2003. Soil fertility management and insect pests: Harmonizing soil and plant health in agroecosystems. Soil and Tillage Research 72(2):203–211. http://dx.doi.org/10.1016/S0167-1987(03)00089-8

Arnalds A. 2004. Carbon sequestration and the restoration of land health. Climatic Change 65(3):333–346. http://dx.doi.org/10.1023/B:CLIM.0000038204.60219.0a

Barbier EB. 2010. Poverty, development, and environment. Environment and Development Economics 15(6):635–660. http://dx.doi.org/10.1017/S1355770X1000032X

Beattie B; Taylor CR. 1993. The Economics of Production, Reprint. ed. Krieger Pub. Co, Florida, USA.

Bernoux M; Feller C; Cerri CC; Eschenbrenner V; Cerri CEP. 2006. Soil carbon sequestration. In: Roose E; Lal R; Feller C; Barthès B; Stewart R. (eds.), Soil Erosion and Carbon Dynamics. CRC Press, Boca Raton, pp. 13–22.

Bowe C; van der Horst D. 2015. Positive externalities, knowledge exchange and corporate farm extension services; a case study on creating shared value in a water scarce area. Ecosystem Services 15:1–10. http://dx.doi.org/10.1016/j.ecoser.2015.05.009

Brey R; Bergland O; Riera P. 2011. A contingent grouping approach for stated preferences. Resource and Energy Economics 33(3):745–755. http://dx.doi.org/10.1016/j.reseneeco.2011.03.003

Brooker RW; Bennett AE; Cong WF; Daniell TJ; George TS; Hallett PD; Hawes C; Iannetta PPM; Jones HG; Karley AJ; Li L; Mckenzie BM; Pakeman RJ; Paterson E; Schöb C; Shen J; Squire G; Watson CA; Zhang C; Zhang F; Zhang J; White PJ. 2015. Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytologist 206(1):107–117. http://dx.doi.org/10.1111/nph.13132

Brookfield H; Stocking M; Brookfield M. 2002. Guidelines on agrodiversity assessment. In: Brookfield H; Padoch C; Parsons H; Stocking M. (eds.) Cultivating Biodiversity: Understanding, Analysing and Using Agricultural Diversity. ITDG Publishing, London, UK. pp. 41–56.

CNT (Center for Neighborhood Technology). 2010. The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits. 80 p. http://bit.ly/1dSO2D3

Dallimer M; Stringer L; Orchard S; Osano P; Njoroge G; Wen C. 2016. Economics of Land Degradation (ELD) Kenya Project Report. Costs and benefits of sustainable soil fertility management in Western Kenya. Report for the economics of Land Degradation Initiative. 40 p. http://bit.ly/2pnetHt

Day J. 2008. The debate over organic verses chemical fertilizers. Today's Homeowner with Danny Lipford [on-line]. www.todayshomeowner.com/debate-over-organic-chemical-fertilizers/

de Bruin K; Goosen H; van Ierland EC; Groeneveld RA. 2013. Costs and benefits of adapting spatial planning to climate change: lessons learned from a large-scale urban development project in the Netherlands. Regional Environmental Change 14(3):1009–1020. http://dx.doi.org/10.1007/s10113-013-0447-1

Diamond PA; Hausman JA. 1994. Contingent valuation: Is some number better than no number? Journal of Economic Perspectives 8(4):45–64. http://dx.doi.org/10.1257/jep.8.4.45

Dwyer JF; Mcpherson EG; Schroeder HW; Rowntree RA. 1992. Assessing the Benefits and Costs of the Urban Forest. Journal of Arboriculture 18(5):227–234. http://bit.ly/2o7hvOT

Ekins P. 1993. Economic Values and the Natural World by David Pearce, Review. Int. Aff. 69, 774–775.

Ellis PR; Putt SN. 1981. The epidemiological and economic implications of foot-and mouth disease vaccination programme in Kenya. Consultancy Report to the Government of Kenya. Consultancy Report to the Government of Kenya.

Government of Kenya. 2013a. Kakamega First County Integrated Development Plan 2013-2017.

Government of Kenya. 2013b. Siaya County Integrated Development Plan 2013-2017.

Government of Kenya. 2013c. Bungoma First County Integrated Development Plan.

Henry M; Tittonell P; Manlay RJ; Bernoux M; Albrecht A; Vanlauwe B. 2009. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agriculture, Ecosystems & Environment 129(1–3):238–252. http://dx.doi.org/10.1016/j.agee.2008.09.006

Imhoff M; Bounoua L; Ricketts T; Loucks C; Harriss R; Lawrence WT. 2004. Global patterns in human consumption of net primary production. Nature 429:870–873. http://dx.doi.org/10.1038/nature02619

Lal R. 2015. Restoring soil quality to mitigate soil degradation. Sustainability 7:5875–5895. http://dx.doi.org/10.3390/su7055875

Lal R. 2008. Carbon sequestration. Philosophical Transactions of the Royal Society B. Biological Sciences. 363:815–830. http://dx.doi.org/10.1098/rstb.2007.2185

Lindemann WC; Glover CR. 2003. Nitrogen Fixation by Legumes. New Mexico State University. http://bit.ly/2p9GO4w

Manrique A; Manrique K; Nakahodo J. 1993. Yield and biological nitrogen fixation of common bean (*Phaseolus vulgaris* L.) in Peru. Plant and Soil 152(1):87–91. http://dx.doi.org/10.1007/BF00016336

MEA (Millenium Ecosystem Assessment). 2005. Ecosystems and Human Well-Being Synthesis. Island Press, Washinton DC. http://dx.doi.org/10.1016/B978-0-12-409548-9.09206-X

Njira K; Nalivata PC; Kanyama-phiri GY; Lowole MW. 2012. Biological nitrogen fixation in sole and doubled-up legume cropping systems on the sandy soils of Kasungu, Central Malawi. Journal of Soil Science and Environmental Management 3(9):224–230. http://dx.doi.org/10.5897/JSSEM12.056

Nowak DJ; Crane DE; Stevens JC. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4(3):115–123. http://dx.doi.org/10.1016/j.ufug.2006.01.007

One Acre Fund. 2015. Maize-legume intercropping: 2014 Phase 1 and 2 trial report.

Pagiola S; Ramírez E; Gobbi J; de Haan C; Ibrahim M; Murgueitio E; Ruíz JP. 2007. Paying for the environmental services of silvopastoral practices in Nicaragua. Ecological Economics 64:374–385. doi:10.1016/j.ecolecon.2007.04.014

Power AG. 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B. Biological Sciences. 365:2959–2971. http://dx.doi.org/10.1098/rstb.2010.0143

Price GW; Gordon AM. 1999. Spatial and temporal distribution of earthworms in a temperate intercropping system in southern Ontario, Canada. Agroforestry Systems 44(2):141–149. http://dx.doi.org/10.1023/A:1006213603150

Rawls WJ; Pachepsky YA; Ritchie JC; Sobecki TM; Bloodworth H. 2003. Effect of soil organic carbon on soil water retention. Geoderma 116(1–2):61–76. http://dx.doi.org/10.1016/S0016-7061(03)00094-6

Rose D; Dewhurst C; Page W. 1997. The African armyworm handbook. Desert Locust Control Organization, Nairobi, Kenya.

Sain G; Loboguerrero AM; Corner-Dolloff C; Lizarazo M; Nowak A; Martínez-Barón D; Andrieu N. 2016. Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala. Agricultural Systems 151:163–173. http://dx.doi.org/10.1016/j.agsy.2016.05.004

Sandhu HS; Wratten SD; Cullen R; Case B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64(4):835–848. http://dx.doi.org/10.1016/j.ecolecon.2007.05.007

Seeberg-Elverfeldt C. 2010. FAO: Carbon Finance Possibilities for Agriculture, Forestry and Other Land Use Projects in a Smallholder Context - Environment and Natural Resources Management Working Paper. Forestry 34.

Swinton SM; Lupi F; Robertson GP; Hamilton SK. 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. Ecological Economics 64(2):245–252. http://dx.doi.org/10.1016/j.ecolecon.2007.09.020

Tengnas B. 1994. Agroforestry extension manual for Kenya. International Center for Research in Agroforestry, Nairobi, Kenya.

Vanlauwe B; Descheemaeker K; Giller KE; Huising J; Merckx R; Nziguheba G; Wendt J; Zingore S. 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. Soil 1:491–508. http://dx.doi.org/10.5194/soil-1-491-2015

Vanlauwe B; Giller KE. 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystems and Environment 116(1–2):34–46. http://dx.doi.org/10.1016/j.agee.2006.03.016

Veres A; Petit S; Conord C; Lavigne C. 2013. Does landscape composition affect pest abundance and their control by natural enemies? A review. Agriculture, Ecosystems and Environment 166:110–117. http://dx.doi.org/10.1016/j.agee.2011.05.027

Wang ZG; Jin X; Bao XG; Li XF; Zhao JH; Sun JH; Christie P; Li L. 2014. Intercropping enhances productivity and maintains the most soil fertility properties relative to sole cropping. PLoS One 9. http://dx.doi.org/10.1371/journal.pone.0113984

Ward FA. 2012. Cost–benefit and water resources policy: A survey. Water Policy 14(4):250–280. http://dx.doi.org/10.2166/wp.2011.021

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